REDACTED FOR PUBLIC INSPECTION

Hogan Lovells

Hogan Lovells US LLP
Columbia Square
555 Thirteenth Street, NW
Washington, DC 20004
T +1 202 637 5600
F +1 202 637 5910
www.hoganlovells.com

April 1, 2014

VIA ELECTRONIC DELIVERY

Marlene H. Dortch, Secretary
Federal Communications Commission
445 12th Street, SW
Room TW-A325
Washington, DC 20554

Re: **Highly Confidential Treatment**
Declaration of Mark McDiarmid, Vice President of Radio Network Engineering and Development, T-Mobile USA, Inc.
Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions, GN Docket No. 12-268;
Policies Regarding Mobile Spectrum Holdings, WT Docket No. 12-269

Dear Ms. Dortch:

T-Mobile USA, Inc. (T-Mobile) submits the attached Declaration of Mark McDiarmid, Vice President of Radio Network Engineering and Development at T-Mobile, pursuant to the Protective Order in GN Docket No. 12-268 and WT Docket 12-269 and to the Commission's preliminary determination that the Declaration contains Highly Confidential Information protected by that Order. Highly Confidential Information has been redacted from the attached copy, which is appropriate for public inspection.

We have submitted an unredacted version to the Commission and will make the unredacted version available to permissible parties subject to the conditions outlined in the Order. Please do not hesitate to contact the undersigned should you have any questions regarding this Declaration.

Respectfully submitted,

/s/ Trey Hanbury

Trey Hanbury
Counsel to T-Mobile USA, Inc.
trey.hanbury@hoganlovells.com
D 1+ 202 637 5534

Enclosure

Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matters of	)	
	)	
Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions	)	GN Docket No. 12-268
Policies Regarding Mobile Spectrum Holdings	)	WT Docket No. 12-269

DECLARATION OF MARK MCDIARMID

I. Qualifications

1. I, Mark McDiarmid, serve as Vice President for Radio Network Engineering and Development at T-Mobile USA, Inc. (T-Mobile). I joined T-Mobile in 2004 and have served as Vice President since January 2011. I lead several teams of engineers who work to create robust, efficient, and economical radio network designs. My responsibilities include strategy and development of radio spectrum and access network technology, radio system design, and device technology. For example, I was responsible for defining the evolution and system design of T-Mobile's HSPA+ and LTE mobile broadband network, including the design and operationalization of new radio network transport solutions based on IP and Ethernet. I began at T-Mobile as the Director of RF/RAN Engineering and then became the Senior Director, where I led a team of engineers in projects related to systems engineering and strategy.

2. I have 23 years of experience in both domestic and international wireless operations. Prior to joining T-Mobile, I played a key role in the development of several new businesses that provided innovative products and services to the wireless industry. I am also the co-inventor of a

patented signal message prioritization method. I earned a Higher National Certificate in Electrical and Electronic Engineering from Llanelli Technical College in 1987. In 1990, I was awarded a Bachelor of Engineering degree from University College Swansea after completing a thesis specializing in radio frequency design and UHF antenna systems.

3. As head of radio planning and design at T-Mobile, I am responsible for the study, quantification, and prediction of radio frequency propagation. Propagation predictions are employed by T-Mobile for the purpose of setting coverage expectations for customers through on-line map presentations, determining optimal locations for new cell sites, and frequency and spectrum planning. Since joining T-Mobile in 2004, I have led the investment in upgrading the geographic data used by the our propagation analysis tools to include digital terrain models and satellite-derived land-cover models, to improve the accuracy of propagation loss predictions. We have also invested heavily in the validation of these propagation models by collecting radio frequency field measurements in the 2100 MHz, 1900 MHz, and 700 MHz frequency bands. In addition to collecting field measurement data directly, we have engaged the services of third-party companies to support the independent validation of propagation predictions with the objective of ensuring accuracy and reliability. As a team, we have gained knowledge about radio frequency propagation from these measurement campaigns and built expertise in T-Mobile's radio planning and engineering organizations. This experience is set forth in this declaration and where appropriate, qualified with supporting data from third parties.

II. Executive Summary

4. In this declaration, I address some of the characteristics of low-band spectrum that make this scarce resource uniquely valuable to mobile broadband network operators. First, I discuss the technical attributes of low-frequency spectrum and high-frequency spectrum.

Radiofrequency radiation exhibits much greater path loss at high frequencies than at a lower frequencies, and we have observed in the field that the comparative real-world decay of high-band signals relative to low-band signals is even greater than theory would predict. These effects are not intended to suggest that low-band spectrum is intrinsically superior to high-band spectrum: wireless carriers benefit from a mix of low- and high-band spectrum assets for cost-effective deployments. Rather, the predicted and observed differences between and low- and high-band signal propagation simply mean that a dearth of low-band spectrum imposes constraints on the ability of a wireless carrier to cost-effectively serve customers across multiple operating environments.

5. Second, I discuss how the deployment of low-band spectrum in conjunction with mid-band spectrum improves network performance and reliability, expands coverage, and decreases capital and operating expenses. We have extensively studied how best to deploy the limited 700 MHz spectrum holdings T-Mobile has applied to acquire from Verizon Wireless in an application now pending before the Commission. One such study revealed that low-band spectrum would allow us to substantially improve commercial in-building coverage from [redacted] of POPs throughout the market, and from [redacted] of POPs in the urban core. The same study showed similar improvements in in-building residential coverage, where low-band spectrum allowed us to move from a baseline of [redacted] in the urban core, and from [redacted] across the economic area, even as we [redacted]. Study after study shows similar results. Because mid-band spectrum's weaker in-building capabilities and poorer propagation over distance make coverage expansions and improved in-building performance comparatively expensive to implement, operating

exclusively with higher-frequency spectrum has required T-Mobile to make disproportionately large capital expenditures relative to carriers with a more balanced spectrum portfolio of low- and high-band spectrum. These expenses are one of the reasons why our cash cost (total service revenues minus EBITDA) per user per month is higher than that of either AT&T or Verizon, even though our network footprint is smaller than the footprint of the two dominant providers.[1]

6. Third and finally, I review how the differences in coverage, in-building penetration, and expense affect the ability of wireless carriers to acquire and retain customers. Consumers value in-building and wide-area coverage, especially at home. In an attempt to quantify how our in-building coverage performance affects our customer base, we have reviewed monthly churn data developed from surveys of [redacted] departing T-Mobile customers. Our analysis demonstrates that, over the course of 2013, [redacted] Specifically, approximately [redacted] of deactivating customers switch for indoor coverage reasons, which equates to a loss of approximately [redacted] subscribers per month. Extrapolating this statistically significant deactivation survey data across our base allows us to estimate that approximately [redacted] of subscribers, or [redacted] T-Mobile customers, may experience in-home coverage issues which, as explained above, relate directly to T-Mobile's limited access to low-band spectrum. While competitive pricing, handset availability and cost, and customer service remain important components of high quality service and remain important priorities for T-Mobile, [redacted] In my capacity as Vice President for Radio Network Engineering and Development at T-Mobile and based on my extensive

[1] UBS Investment Research, US Wireless 411: Version 50, 24 (Nov. 13, 2013).

experience with many different types of network design and deployment models, [redacted].

III. Technical Performance Characteristics of Spectrum

7. As demonstrated by both theoretical path loss formulas and empirical measurements, electromagnetic signals generally exhibit greater path loss as frequency increases. In addition, reflections off large objects, diffraction around or over objects, and scattering after collision with smaller objects also affect different frequencies differently, with higher-frequencies suffering greater signal interruption and distortion over distances than lower-frequencies. For mobile wireless communications, which worldwide are typically in the 450 MHz to 2.7 GHz range, radiofrequency operations in spectrum bands below 1 GHz exhibit much lower path losses and less susceptibility to signal disruption than operations on wireless broadband in spectrum bands above 1 GHz. As a simple example using the theoretical free space path loss equation, the use of a frequency that is twice as high as another frequency produces 6 dB less energy at the receiver than the lower-frequency band for a receiver the same distance away. In less technical vernacular, this means that the energy received using the higher frequency signal is just 25% of the energy received using the lower frequency signal. For reference, the AWS band uplink (centered at 1732.5 MHz) is roughly double the frequency of the cellular band uplink (centered at 836.5 MHz). Because AWS frequencies are roughly twice as high as cellular frequencies, the energy received from the AWS transmitters used by T-Mobile is roughly 25% of the energy received from a similar low-band transmitter in the 850 MHz cellular bands used by Verizon and AT&T, assuming free-space path loss characteristics and the same propagation distance. As I

will discuss later, measurements of real-world deployments have shown that the actual propagation advantage of low-band spectrum is even greater than theory predicts.

8. While no model perfectly describes the variations in performance between different frequency bands, the calculated and observed technical characteristics of radiofrequency emissions strongly influence network design. Wireless carriers consider the frequency resources and bandwidth available to support the network as they strive to balance coverage and capacity objectives. The deployed frequency and its associated propagation characteristics are considered in virtually every major element of a wireless system's network architecture, including the most fundamental steps (such as the determination of coverage objectives and signal thresholds that determine the average user experience) and the more detailed aspects of RF design (including site selection, antenna type, height, orientation, tilt, and power).

9. Although low-band spectrum has superior propagation characteristics relative to high frequencies, the optimum scenario for a carrier is to have a mix of spectrum assets in its portfolio; low frequency bands provide a base layer of capacity as well as greater coverage, reach, and in-building penetration; high frequency bands provide increased capacity in denser environments. Said another way, the primary disadvantage of low-band spectrum is that there is not as much of it compared to high-band spectrum. The largest contiguous low frequency band in the United States today is the cellular band at 25+25 MHz, compared to 45+45 MHz in the AWS band and 65+65 MHz in the PCS band. Thus, deploying wide-band, high-speed, high-capacity LTE channels of 15 or 20 MHz is only practical in the higher frequency bands. Together, this mix of low and high bands can provide both reliable coverage and high-speed, high-capacity connections for consumers compared to what a carrier whose spectrum assets are homogeneous can offer. In addition, the introduction of carrier aggregation in LTE allows low-

band and high-band spectrum to be combined seamlessly to provide the wireless subscriber with the coverage and capacity advantages that each band offers. In effect, use of both low-band and high-band frequencies produces a result that is greater than the sum of its parts.

10. In addition, across nearly every element of contemporary network design, the availability of low-band spectrum affords a wireless broadband provider greater latitude in network architecture and design as compared to a provider that is using only high frequency spectrum to provide both capacity and coverage. Notably, carriers with greater access to low-band spectrum have the ability to rely on its superior in-building coverage and to serve more consumers while spending less on network equipment in areas where extra capacity is not needed.

11. Less well understood, but equally useful from a network-design perspective, is the benefit of flexibility – through careful site selection, antenna positioning, power variation, and other considerations – to use low-band spectrum in a manner that emulates the shorter propagation characteristics of high-band spectrum for resolving inter-site interference when adding sites to increase capacity. In effect, the coverage advantages of low-band spectrum can be easily traded for capacity gains, giving operators greater flexibility in meeting both coverage and capacity objectives. This flexibility is especially consequential during periods of skyrocketing consumer demand for data, which grew 81% during 2013.[2] But whereas low-band cells can be "split" or deployed in a manner to reduce propagation and thereby increase capacity, high-band cells are typically constrained by their more limited coverage. In other words, trading the capacity

[2] *See* Cisco, *Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2013–2018* (Feb. 5, 2014), http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white_paper_c11-520862.pdf; *see also* Ericsson, *Eriscsson Mobility Report* (Feb. 2014), http://www.ericsson.com/res/docs/2014/ericsson-mobility-report-february-2014-interim.pdf.

advantages of high-band spectrum for coverage gains is constrained by physics and the practical limitations of radio frequency design; power limitations, antenna heights, and less favorable propagation characteristics of high frequency spectrum restrict the ability of wireless operators to deploy it in a manner that emulates the in-building and wide-area coverage performance of lower-band spectrum.

12. Given these technical realities, lack of access to low-band spectrum has had important quality of service considerations for consumers and economic consequences. Carriers with a limited number of low-band spectrum licenses are forced to deploy much denser infrastructure, which adds considerable delay and expense to the process of providing and improving coverage.

IV. Technical Advantage of Access to Low-Band Spectrum

A. Indoor Coverage

13. Low-band signals provide a consumer experience indoors superior to high-frequency signals for two primary reasons. First, low-frequency signals are stronger when they reach obstacles because propagation loss is proportional to the square of the frequency; therefore, low-frequency signals attenuate less. Second, when low-frequency signals encounter building materials or other obstacles, which attenuate, reflect, and obstruct the passage of radio signals through walls, the effects of obstructions on low-frequency signals are less pronounced than on higher-frequency signals. Numerous studies have demonstrated that low-band spectrum experiences significantly less penetration loss than higher-frequency spectrum when traveling through building walls, yielding improved consistency and reliability of indoor coverage. For example, two of our vendors independently concluded that low-band spectrum experiences 2 to 3 dB less attenuation than high-band spectrum when passing through common building materials to provide coverage inside buildings.

14. In January 2014, T-Mobile's internal national RF planning team performed a network design study for the Dallas, Texas Basic Economic Area (BEA). Dallas's urban area and surrounding suburbs are mostly flat and homogenous, and can be considered representative of several major American metropolitan areas. In this study, the RF team modeled the differences in coverage capabilities between an LTE deployment in the AWS band and one in the 700 MHz band. The study examined coverage reaching consumers outdoors, in their cars, in residential buildings, and in commercial buildings. For the purposes of comparison, a baseline AWS network using existing 1.9 GHz facilities was designed and a baseline coverage analysis was run at each of the four levels of coverage by using penetration losses of 6 dB, 14 dB, and 20 dB relative to outdoor coverage for in-car, residential in-building, and commercial in-building, respectively. With this baseline design, T-Mobile could provide excellent outdoor coverage for a high percentage of the population, although a few sparsely populated areas were difficult to reach with any efficiency. For example, throughout the BEA, the baseline design for mid-band coverage provided [redacted] of POPs with coverage outdoors and [redacted] with coverage in cars. In the core population centers of the economic area, the network design could offer [redacted] of POPs outdoor coverage and [redacted] in-car coverage. While this mid-band design allowed us to achieve near-universal outdoor coverage, indoor coverage proved less reliable. In the core areas, our baseline design made coverage available at the signal level required for residential buildings in areas covering only [redacted] of POPs and at the signal level required for commercial buildings in areas covering just [redacted] of POPs. Across the entire BEA, the baseline design provided residential indoor coverage to an area covering only [redacted] of POPs and commercial building indoor coverage to an area covering merely [redacted] of POPs.

15. For the purpose of comparison, the network team then created a 700 MHz design intended to reduce the number of sites required while simultaneously improving the reliability and availability of indoor coverage. For the latter objective, the design thresholds for residential and commercial in-building coverage were increased by another 6 dB (*i.e.*, effectively quadrupling the received indoor power assumed by our mid-band design) to make the system more robust. That is, the penetration loss threshold for residential in-building was increased from 14 dB to 20 dB and for commercial in-building from 20 dB to 26 dB. The study showed that deploying service across the same area using 700 MHz spectrum would allow T-Mobile to improve commercial in-building coverage considerably – from [redacted] of POPs across the overall BEA, and from [redacted] of POPs in the core areas. In-building residential coverage would also improve significantly, from the baseline of [redacted] in the urban core, and from [redacted] across the BEA. Even more remarkable is that these increases in POPs covered by signals at the in-building thresholds – and simultaneous tightening by 6 dB of those in-building thresholds – were achieved in the 700 MHz band by using substantially less infrastructure: [redacted].

16. Some parties have criticized analyses designed to show the economic advantage of low-band spectrum as failing to include an engineering analysis of costs, ignoring the effect of existing spectrum on network design, and failing to account for relevant real-world factors, such as antenna gain. This analysis reflects our engineers' judgment based on T-Mobile's existing network, as it was designed for a non-advocacy purpose to support T-Mobile's existing spectrum assets. The result is that a low-band overlay could "skip" [redacted] the sites in the high-band design. The full results for the 700 MHz coverage improvement in Dallas are shown in the table and maps below:

[redacted]

[redacted]

[redacted]

17. T-Mobile's national RF planning staff has conducted similar comparisons of low- and mid-frequency spectrum in 22 additional markets across the United States since the beginning of 2014, including markets of varying size, terrain, population density, and average building height and density. In each market analyzed, significant improvements to indoor coverage were achieved both in terms of indoor signal quality and breadth of coverage. In some cases, such as the Washington-Baltimore BEA, [redacted]

[redacted], the 700 MHz design realized substantial improvements that brought the [redacted] by using only [redacted] of the infrastructure as our mid-band network. The overall conclusions of these detailed analyses have been that 700 MHz designs in such disparate markets as Miami, Fresno, Philadelphia, Cleveland, Minneapolis, and Houston, to name just a few, will achieve significant, perceptible, and impactful indoor coverage improvements while using only about [redacted] of T-Mobile's current AWS site count, a substantial savings. In addition, for reasons discussed in greater detail below, this model also offers T-Mobile the ability to greatly expand the size of its overall footprint, bringing coverage to less populated rural areas outside the urban core.

18. Some commenters have argued that the Commission should overlook low-band spectrum's inherent superiority in serving customers indoors because carriers could deploy technology that helps carriers work around the issue, such as small cells. These arguments take an overly optimistic view of the economic viability of large-scale deployments of small cells, under-estimate the challenges and costs of providing backhaul to a large number of small cells, and ignore the current limited capabilities and immaturity of small cell technology.

19. Small cells are an increasingly popular choice for solving capacity problems, but their deployment comes with numerous limitations. Many operators have, for example, used Distributed Antenna Systems (DAS) in discrete projects to improve indoor coverage in densely populated buildings like malls and stadiums when low-band spectrum is not available. DAS rely on a relatively dense network of small cells that are connected by fiber optic cable. The antennas are placed on infrastructure smaller than standard towers, such as utility poles, buildings, or traffic signal poles. These systems, while technically viable, are often economically challenging to implement even when deployed on a relatively limited scale. AT&T, for example, reportedly

spent $10 million on a 950-antenna DAS to provide service at the Mercedes-Benz Superdome in New Orleans in advance of the 2013 Super Bowl.[3] T-Mobile has found, through MetroPCS's experience deploying over 6,000 DAS nodes, that the deployment cost is highly variable, and that to achieve coverage equivalent to a macrocell, the average cost is [redacted] more than that of a macrocell. This level of expenditure is not scalable and, in any case, these design options may not even be possible where venues have made exclusive arrangements with a single provider. Furthermore, a patchwork of cross-jurisdictional regulatory requirements often makes placing a DAS as or even more challenging than siting a tower – particularly because the systems are relatively new and many participants in the regulatory process are less familiar with the technology. The many design challenges and potentially lengthy regulatory approval process for numerous small sites can exacerbate costs, particularly if it becomes necessary to seek building-by-building approval for indoor locations, which may ultimately be expensive or impossible to secure.

20. In addition, the expense of connecting the many nodes of a DAS system with backhaul connectivity can be cost prohibitive or simply not possible in many instances. To offer small cells with service level agreements similar to our macocell sites would require switched Ethernet service that, at 100 Mbps, will cost roughly [redacted] per month per site. A less versatile, data-only level of connectivity to a small cell would result in cost savings, but still require approximately [redacted] per month for a 100 Mbps Internet connection. Meanwhile, lower-cost, lower-bandwidth options of 20 Mbps or less, such as DSL or bonded copper, may not offer

---

[3] *See* Mark Schleifstein, *AT&T finishes Superdome antenna upgrade*, The Times-Picayune (Jan. 6, 2012), http://www.nola.com/business/index.ssf/2012/01/att_finishes_superdome_antenna.html.

sufficient capacity, could still require [redacted] per month per connection, and are often not available. Wireless backhaul is a potential option, but raises issues of spectrum availability and cost that are not easily solved on a large scale at this time.[4] In short, if small cell backhaul is available, and often it is not, the monthly cost is many times more than macrocell backhaul when viewed on the basis of cost per square mile of coverage. Thus, deploying a large number of small cells for the purpose of increasing coverage is currently not economically viable.

21. All of these resource concerns are compounded by the still-evolving small cell equipment ecosystem. As new features continue to be developed in 3GPP that will help improve the economic viability of small cells, such as Self Optimizing Networks and support of non-co-channel operation, it remains unclear whether equipment built to current standards will be produced in quantities resulting in economies of scale. Therefore, a huge investment in small-scale technologies could be quickly up-ended by technological change.

22. Even if cost and the risk associated with deploying an as-yet unsettled technology were not major factors, a massive small cell deployment would still be unable to fully mitigate the problems of operating a mobile broadband network without low-frequency spectrum. Small cell technology continues to face quality challenges, such as difficulty in successfully handing over calls between base stations. As we work to provide reliable, always-available service, introducing whole new categories of potential call quality issues would be counterproductive. Furthermore, the coverage improvements resulting from small cells offer no benefit to the rural

[4] *See, e.g., Comments of MetroPCS Communications, Inc.*, WT Docket No. 10-153, RM-11602 (filed Oct. 5, 2012).

communities where low-band spectrum is the only practical and economical solution for reaching large, sparsely populated areas of the country.

23. Other innovative solutions allow users to improve their indoor calling experience and reduce their overall costs, but have their own limitations. T-Mobile has pioneered in-home solutions, such as WiFi calling, which can work well, but place some burden on customers to (i) identify the problem, (ii) establish wireless connectivity at home, and (iii) in many cases bear some of the cost for the equipment or its installation. Small cell devices are, therefore, an excellent option for many consumers, but they in no way obviate the need for low-band spectrum. For example, in T-Mobile's network only [redacted] of voice calls are carried over WiFi, indicating that while WiFi is a solution for a limited number of indoor coverage issues, it certainly is not a substitute for more robust coverage. Relying on small cells raises the cost of competing with carriers that have access to spectrum below 1 GHz. Moreover, carriers that have access to spectrum below 1 GHz in addition to high-band holdings are able to solve indoor coverage issues with far less reliance on elaborate add-on technologies and the challenges, inconveniences, and costs those technologies bring.

B. Coverage over distance

24. All mobile wireless signals deteriorate as they travel from the tower to the mobile handset. Numerous studies have verified in practice the basic fact that lower-frequency spectrum has a significant path loss advantage over higher-band spectrum in all kinds of terrain. The general mathematical relationship between path loss, distance, and frequency is expressed in the free space path loss formula as:

$$FSPL = \left(\frac{4\pi df}{c}\right)^2$$

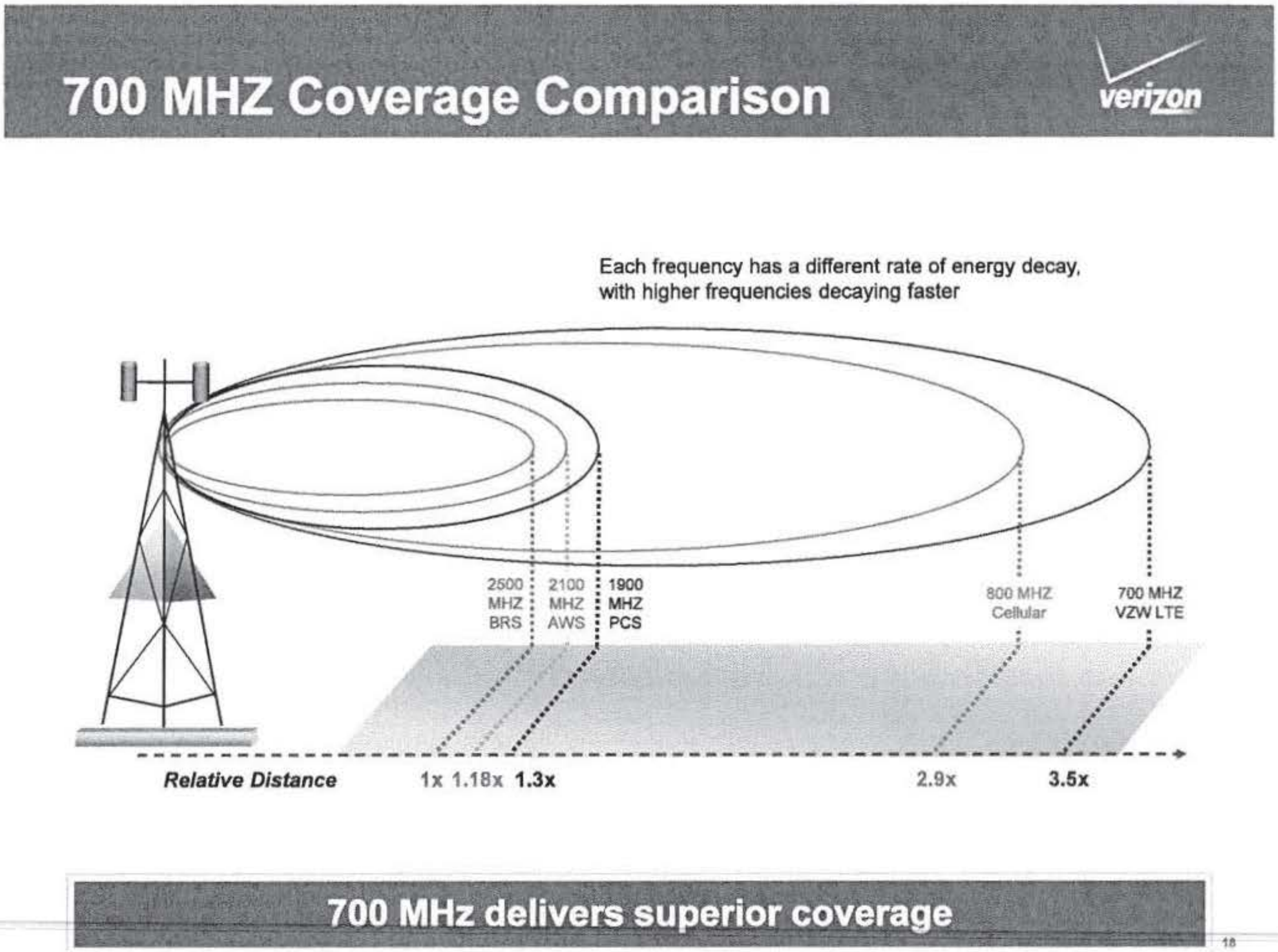
Or expressed logarithmically, as is more common in the field of radio frequency engineering:

$$FSPL(dB) = 20 \log(d) + 20 \log(f) - 147.55$$

where d is the distance between mobile and base stations in meters and f is the spectrum frequency in hertz. Note that in the linear form of this simple expression, it is easy to see that path loss is proportional to the square of distance as well as the square of the frequency. Decades of research have produced numerous empirical improvements to this formula that better account for real-world effects such as terrain, antenna heights, man-made clutter, land use, weather, diffraction, and reflections; but all empirical models point to the same conclusion demonstrated by this most fundamental formula: signals traveling over higher-frequency spectrum decay faster than they would over low-band spectrum.

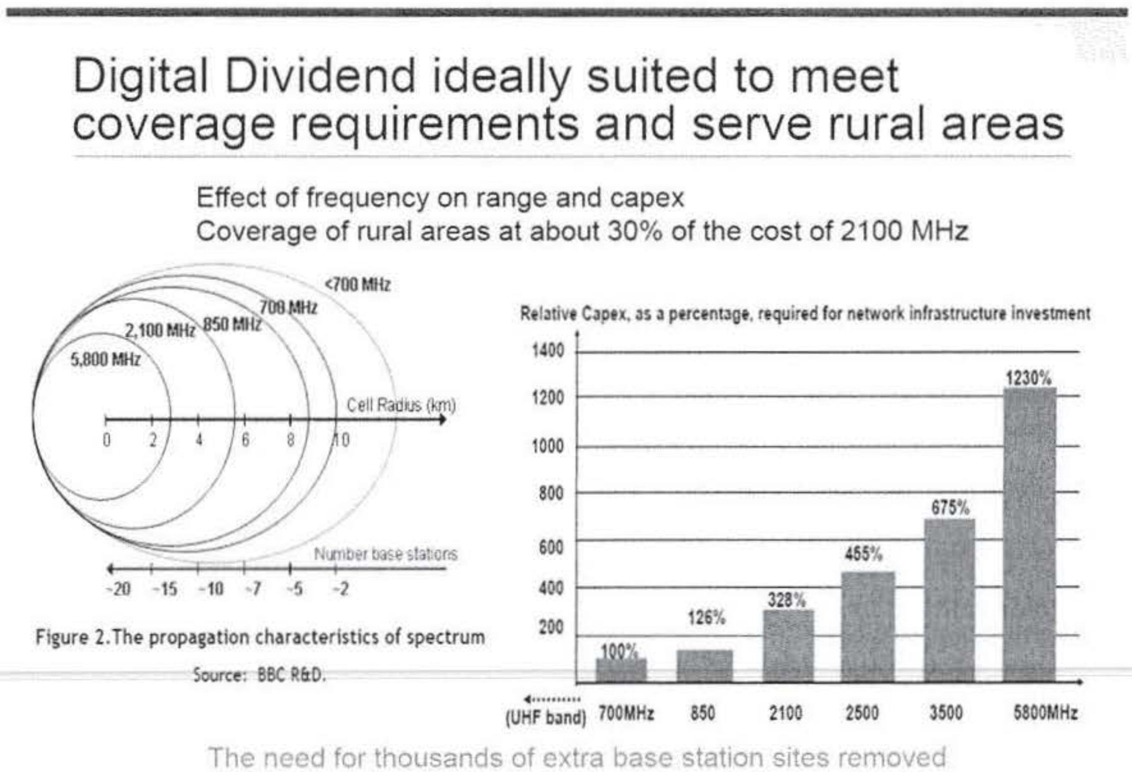
25. Simply stated, when signals travel further, as low-band signals do, we can construct networks of larger cells and use fewer sites to cover the same area. A graphic produced by Verizon shows the relative energy loss over distance of different frequencies in an effort to make this idea more concrete:[5]

[5] Presentation of Tony Melone, Executive Vice President and Chief Technology Officer, Verizon Wireless, Raymond James 32nd Annual Institutional Investors Conference at 18 (Mar. 9, 2011).



26. While this illustration provides some sense of the significant differences between bands, it actually understates the problem by giving the false impression that 700 MHz coverage is 3.5 times the coverage offered by 2.5 GHz. In fact, in Verizon's theoretical, flat-earth representation, the tower is at the center of a circular coverage area whose size is proportional to the square of the radius. Thus, comparing the coverage areas shows that it would take roughly 8 cell sites using 1.9 GHz spectrum to cover the same area as one base station using 700 MHz, and

at least 13 cell sites at 2.5 GHz to cover the same area as one 700 MHz tower.[6] This point is clearly understood and agreed throughout the industry, as shown on this May 2011 slide produced by Qualcomm which touted the benefits of low frequency "Digital Dividend" spectrum for mobile broadband use:[7]



[6] For example, the relative areas theoretically covered by 1.9 GHz and 700 MHz spectrum are $\pi*1.3^2 = 5.3$ and $\pi*3.5^2 = 38.5$ so the ratio in terms of area is 38.5/5.3 or 7.25:1. Rounding up, this leads to 8 sites at 1.9 GHz to cover the same area as one 700 MHz site. Similarly, the area ratio between 2.5 GHz and 700 MHz is 12.25, resulting in at least 13 sites required to cover the same area.

[7] *See* QUALCOMM Incorporated, *Harmonization of the Digital Dividend: Perspectives from the Asia Pacific Region*, at 6 (May 2011), *available at* http://www.itu.int/ITUD/tech/events/2011/Broadcasting_Hanoi_May11/Presentations/Hanoi_May11_Session7_Qualcomm.pdf, *cited by Reply Comments of T-Mobile*, WT Docket No. 12-269, at 6 (filed Jan. 7, 2013), *available at* http://apps.fcc.gov/ecfs/document/view?id=7022099939.

27. Of course, real-world radiofrequency design considerations often diverge from theoretical flat-earth analysis for a variety of reasons. In the study described in paragraphs 14 through 16 we accounted for considerations such as antenna gain, terrain, morphology and clutter, whose effects tend to change the theoretically calculated coverage advantage of low-band spectrum. Some parties have claimed that ignoring these "real-world" effects has inflated estimates in the record of the coverage advantage of low-band spectrum relative to high-band; real-world drive tests designed to make a fair comparison and quantify the coverage advantage of low-band have shown that this concern is unfounded. According to a field study and analysis conducted by [redacted] in 2013, propagation differences in field measurements are even greater than theory suggests. [redacted] 2013 analysis for T-Mobile was based on extensive data from drive tests in urban, suburban, and rural morphologies. The tests used transmitters at each frequency that were co-located, and the conclusion was that the measured propagation advantage of 700 MHz spectrum relative to AWS was 2 dB to 4.5 dB greater than the free space loss equation predicts, with suburban areas experiencing the greatest increase over theory. While our design objective had been to improve in-building coverage, we determined that, by transitioning to low-band spectrum, we could provide high quality coverage to the [redacted] of the mostly rural consumers who do not currently receive coverage under our mid-band baseline. And we realized these gains using approximately [redacted] of base stations required by the mid-band baseline model, making it much more cost effective to overlay our existing coverage footprint as well as allowing us to expand coverage into areas with low population density. These savings proved achievable in models of real-world, high-capacity urban markets across the country. In study after study, we found that using low-band spectrum cut our infrastructure needs [redacted] while simultaneously improving coverage in urban, suburban, and rural areas.

28. To some degree, these modeling exercises were guided by the realities of our existing networks, where our design and siting choices had been driven by our mid-band spectrum holdings. We expect that a greenfield deployment not tied to any legacy investments could yield even more significant savings.

V. Low-band spectrum confers significant economic advantages

29. Because mid-band spectrum's weaker in-building capabilities and poorer propagation over distance make coverage expansions comparatively expensive to implement, operating exclusively with higher-frequency spectrum requires disproportionately large capital expenditures (CAPEX). CAPEX, as a financial measure of network deployment, includes spending on system/network assets and non-network assets such as vehicles and buildings. Spectrum licenses and related expenditures are not included in CAPEX. Publicly available financial data shows that T-Mobile spends $90.79[8] per customer year on CAPEX – nearly as much per customer as Verizon, which spends $91.68[9] per customer per year – even though T-Mobile's coverage footprint remains much smaller. Large CAPEX needs, therefore, affect T-Mobile's investment decisions more significantly than the largest carriers.

30. Deploying mid-band networks contributes to these costs. Larger cells yield more coverage with fewer base stations, reducing the overall infrastructure cost to cover a geographic area. One commenter has argued that operators' roughly equal cell densities in some areas is

---

[8] $4,240,000,000 in annual CAPEX/ 46,700,000 total customers. *See Investor Quarterly Fourth Quarter 2013*, T-Mobile (Feb. 2014); Press Release, T-Mobile, *T-Mobile US Reports Preliminary Fourth Quarter 2013 Customer Results* (Jan. 8, 2014).

[9] $9,425,000,000 in annual CAPEX/ 102,800,000 total retail connections. *See Investor Quarterly Fourth Quarter 2013*, Verizon (Jan. 21, 2014).

direct evidence that low-band spectrum offers no true advantage. That analysis ignores the relative coverage provided by each operator in those areas. For example, our internal count shows that T-Mobile operates about [redacted] cell sites, compared to Verizon's 46,000 cell sites as reported by UBS.[10] Our internal measurements show that T-Mobile currently provides coverage over roughly [redacted].[11] Using on-line coverage maps, T-Mobile estimates that Verizon, on the other hand, covers approximately 2.2 million square miles, or one tower per 47 square miles of coverage. Verizon's primarily low-band deployment appears to [redacted] in its use of infrastructure as T-Mobile's current, mid-band design. These numbers are roughly consistent with the results of T-Mobile's modeling that also demonstrated a [redacted] coverage advantage for low-band spectrum, as well as coverage improvements at that site ratio. Looking at these statistics, it becomes very clear that T-Mobile's significant investment in infrastructure has not translated into a larger coverage area.

31. Our average cost to add a cell site depends on a number of factors but ranges between [redacted] for adding a band to an existing site and between [redacted] for building a new greenfield site. If we establish [redacted] cell sites every time Verizon installs one, our excess costs traceable to lacking low-band spectrum reach nearly [redacted] after as few as [redacted] sites. The significant – and often disproportionate – costs we incur in expanding our geographic reach can make economic sense in dense urban areas, where many subscribers

---

[10] UBS Investment Research, US Wireless 411: Version 50, 29 (Nov. 13, 2013).

[11] [redacted].

benefit from each investment. But it is much more difficult to justify these disproportionate infrastructure expenses in rural areas where each base station will serve significantly fewer people.

32. Even where we are able to absorb the cost of operating more base stations per square mile, T-Mobile is often not able to navigate the contractual and regulatory hurdles necessary to establish such a dense network. The need for more towers creates complex design problems and non-infrastructure costs, such as increased expenses for tower siting and regulatory compliance. In practice, the cost to provide comparable service with incumbents operating on low-band spectrum can be enormous—one of the reasons why our cash cost (total service revenues minus EBITDA) per user per month is higher than that of either AT&T or Verizon.[12]

33. The unique propagation characteristics of low-band spectrum also confer advantages in increased flexibility in placing equipment, which can reduce costs, accelerate deployment, and increase coverage. Areas that had been previously difficult to cover because of tower siting issues can in many cases be served more easily when, because of the superior reach of low-band spectrum, search rings to identify suitable base station locations expand such that RF designers have more latitude deciding where base stations can be placed. This type of flexibility can be particularly important in efforts to cover residential areas with restrictive zoning laws. It also facilitates competition in tower selection should a particular tower owner seek excess rent because of their control of a highly desired location.

34. The expense and time associated with providing comparable coverage on higher-band spectrum has had a measurable and well-documented impact on T-Mobile's ability to retain

[12] UBS Investment Research, US Wireless 411: Version 50, 24 (Nov. 13, 2013).

existing customers and acquire new subscribers. [redacted]. To illustrate, [redacted] of consumers experiencing coverage issues report that their homes were the primary place they experienced a problem and approximately [redacted] of deactivating customers switch for indoor coverage reasons, which equates to a loss of approximately [redacted] subscribers per month.[13]

35. We estimate that approximately [redacted] of subscribers, or [redacted] T-Mobile customers, may experience in-home coverage issues which, as explained above, relate directly to T-Mobile's limited access to low-band spectrum.[14] While competitive pricing, handset availability and cost, and customer service remain important components of high quality service and remain important priorities for T-Mobile, [redacted].

36. Based on my experience leading T-Mobile's radio network engineering and development teams and my familiarity with how directly the quality of network operations influences customer perceptions, I can attest that consumers are extremely sensitive to improvements in coverage and in-building penetration. Indeed, our monthly survey data has consistently shown

[13] [redacted].

[14] [redacted]

that coverage gains are one of the best investments we can make to reduce churn, raise revenue, and improve our subscribers' experience. In addition to the monthly survey data described above, we also employ [redacted], a third-party firm specializing in consumer engagement, to evaluate our efforts to improve customer retention and satisfaction. Based on [redacted] monthly 20-minute consumer surveys that include questions on coverage, service, billing/payment, handsets, and website and retail interactions, [redacted] customer-relationship assessment assigns customers an index score, a tool commonly used in a variety of industries. That score reflects a customer's overall view of T-Mobile's performance, the likelihood they will recommend T-Mobile to others, the likelihood they will continue to use T-Mobile, and a "competitive advantage" score. Based on this data, [redacted] develops a penalty-rewards analysis that shows how much T-Mobile can improve customer satisfaction by implementing various service improvements. These assessments generate insight into which aspects of our service really matter to our customers and allow us to optimize our efforts to meet those priority needs.

37. In a penalty-rewards analysis using survey data gathered during the fourth quarter of 2012, for example, we examined a variety of potential areas of focus for customers, including customer care (resolving a problem or answering a question on a customer's first call); competitive pricing of monthly calling plans; plan offerings without gimmicks or hidden charges; and coverage. For each of these areas, we used our [redacted] surveys to examine the impact of customers' satisfaction with various individual aspects of our service on their overall impression of our performance. When this study was conducted, T-Mobile's [redacted]

[redacted]

38. [redacted] In short, improving coverage increases customer satisifcation.

39. [redacted]. Our internal customer satisifaction data, therefore, demonstrates the importance of providing superior outdoor and in-buiding coverage to our customers.

VI. Conclusion

40. Low-band spectrum provides benefits to mobile broadband network operators. It improves the consistency and reliability of indoor coverage, even in difficult terrain, without the costs, complexity, or limitations associated with small-cell technology. Low-band spectrum also yields better coverage over distance, reaching rural and underserved areas with less dense infrastructure. Our internal design studies, customer satisfaction measurements, and third-party reports confirm the technical and economic distinctions between spectrum above 1 GHz and spectrum below 1 GHz.

/s/Mark McDiarmid

Mark McDiarmid
Vice President, Radio Network

Engineering and Development
T-Mobile USA, Inc.

April 1, 2014